Chapter 7
Thermal Spray Coating Application

7-1. Introduction

a. Thermal spray coatings for corrosion protection of steel may be applied by several different methods, including wire flame spray, arc spray, and powder flame spray. Each process has its inherent advantages.

b. The best application process for a given job depends on the coating material to be applied and the size of the job. Contracts should permit the contractor to select the application process or processes to be used.

c. The ambient conditions under which the thermal spray coating will be applied must be within the specified range.

d. The applicator must employ the proper application techniques, and the equipment must be properly set up and operated within the manufacturer's parameters to ensure the application of a quality coating.

e. The sequencing of the application must occur in a timely manner to ensure that the receiving surfaces are still clean and free of rust bloom.

7-2. Ambient Conditions Required for Thermal Spray

a. Air temperature, humidity, and dew point. Generally speaking, there are no ambient air temperature limitations on the application of thermal spray coatings. Unlike paint coatings, thermal spray is not affected by extremes of temperature. Although there are no theoretical limits within the normal ambient temperature range on the application of thermal spray coatings, in practice there are limits within which the applicator will be effective and safe. Because thermal spray coatings are typically sealed with paint-type coatings, there may be practical limits based on the temperature requirements of the sealer. Most epoxy-type sealers can be applied when ambient temperatures are between 7 and 32 °C (45 and 90 °F). With special precautions, vinyl-type sealers can be applied at temperatures between -18 and 38 °C (0 and 100 °F). However, the application of sealers and paints can often be delayed, provided the thermal spray coated surface remains clean and dry. As with painting, the relative humidity and dew point can affect the quality of the applied coating and may also affect improperly stored or packaged thermal spray feedstock materials. In very humid environments, blast cleaned steel may rerust or exhibit a rust bloom more rapidly than under normal ambient conditions. Thermal spray coatings should never be applied after the appearance of rust bloom on the surface. The dew point is the temperature at which moisture will condense. Condensation and the formation of rust bloom on the steel surface are very likely to occur at or near the dew point. Because of this problem, it is required that the ambient temperature be at least 3 °C (5 °F) above the dew point. Temperature, humidity, and dew point cause problems if thermal spray feedstock is not properly stored. All of the active metal wires oxidize. The oxide film can cause feed problems in both flame and arc equipment. Extreme temperature changes may also cause zinc and zinc-aluminum alloy wire to recrystallize and become brittle. Powder storage is even more critical than wire storage. Moisture in the powder will have an adverse impact on flow in the powder feed systems. Thermal spray wires and powders should be securely sealed and protected from moisture intrusion to prevent oxidation of the material.

b. Steel temperature. Temperature changes in heavy structural steel often lag behind changes in the ambient temperature. This may cause particular problems in the morning hours when the temperature is near the dew point. Steel that is in contact with soil or water may also remain colder than the surrounding air temperature, causing problems with condensation and rerusting of the steel. Provided that the surface has not rerusted, the temperature of the steel is of little consequence. When using combustion spray processes which employ a hydrocarbon fuel gas the surface should be preheated to above 121 °C (250 °F) to prevent condensation of water from the flame on the surface as the coating is being applied. The water in the flame is a by-product of the combustion reaction. Preheating the surface is ordinarily accomplished using the thermal spray gun with the material feed turned off, as a torch. Approximately 0.1 to 0.2 m^2 (1 to 2 ft^2) of surface area should be preheated at a time. Arc spraying does not require preheating of the substrate.

7-3. Thermal Spray Application Techniques

Proper spray technique is critical to the success of thermal spray coatings. Poor spray technique may result in early coating failure due to poor coating adhesion or cohesion, excessive coating porosity, or a high oxide content. Poor spray technique may also result in highly variable coating thicknesses, including areas that are deficient.

a. Spray pattern. Manually applied thermal spray coatings should be applied in a block pattern measuring approximately 60 cm (24 in.) on a side. Each spray pass should be applied parallel to and overlapping the previous pass by approximately 40 percent. Successive spray coats should be applied at right angles to the previous coat until the desired coating thickness is achieved. Approximately 50 to 75 μm (0.002 to 0.003 in.) of coating should be applied per spray pass. In no case should less than two spray coats applied at right angles be used to achieve the specified coating thickness. This procedure is designed to produce the most uniform coating thickness of the best possible quality. A larger block pattern may cause the applicator to overreach, resulting in coating nonuniformity. Wire flame spray guns produce a small round spray pattern, allowing the applicator to maintain the same wrist orientation (vertical) on each spray coat. Alternatively, the wire flame spray applicator may apply the second spray coat with the wrist oriented in the horizontal plane. Arc and powder flame spray guns with fan air caps generally produce a much larger oval shaped spray pattern. The powder flame and arc spray operators generally must spray the second coat with the wrist oriented 90 deg to that used for the first spray coat. The arc and powder flame spray guns should never be used to apply coating moving in a direction parallel to the long access of the oval shaped spray pattern. Most powder flame and arc spray guns may be fitted with optional air caps that will produce different size and shape spray patterns. These fittings allow the operator to apply a uniform coating to components with complex shapes. The large oval fan pattern is best suited to spraying large flat substrates. Small round spray patterns are better suited for coating complex shapes or small objects. Table 7-1 shows the nominal spray widths produced by several types of spray guns.

b. Standoff distance. Standoff distance is dependent on the type and source of spray application equipment used. The maximum standoff distance for most equipment is generally on the order of 15 to 25 cm (6 to 10 in.). Table 7-1 shows nominal standoff distances for various types of equipment. Excessive standoff distance will produce a more porous and oxidized coating with reduced cohesion and adhesion. The higher porosity may be attributed to the greater degree of cooling and the lower velocity that the thermal spray particles experience prior to impact. Adhesion is directly proportional to the kinetic energy of the spray particles, and the kinetic energy varies as the square of the particle velocity. The cooler, slower impacting particles will not adhere as well to each other or to the substrate, resulting in a weaker, less adherent coating. Excessive standoff distance may occur because the applicator is not adequately familiar with the requirements of the equipment or due to fatigue or carelessness. Increased standoff distance may result from the applicator's arm or wrist arcing during application. It is very important that the applicator's arm moves parallel to the substrate to maintain a consistent standoff distance. Holding the thermal spray gun too close to the surface may result in poor coverage and erratic coating thicknesses because of the reduced size of the spray pattern. It is very important that the applicator's arm moves parallel to the substrate while maintaining a constant standoff distance.

Table 7-1
Nominal Standoff Distances and Spray Widths

Thermal Spray Process	Standoff Distance cm (in.)	Spray Width with Regular Air Cap, cm (in.)	Spray Width with Fan Air Cap cm (in.)
Wire flame spray	12.5-17.5 (5-7)	2 (3/4)	Not available
Powder flame spray	20-25 (8-10)	5 (2)	7.5-10 (3-4)
Wire arc spray	15-20 (6-8)	4 (1 1/2)	7.5-10 (3-4)[a]

[a] Newer high production rate wire arc systems may have fan-type air caps that produce spray deposit patterns as wide as 15-25 cm (6-10 in.).

c. Spray angle. The gun-to-surface angle is important because of the generally greater distances that the spray particles travel prior to striking the substrate, producing a situation analogous to the excessive standoff distances already discussed. Porosity, oxide content, and adhesion are strongly affected by spray angle. In some cases, it may be necessary for the applicator to spray at less than 90 deg because of limited access to the surface. In no case should the applicator spray at an angle less than 45 deg. Spray extensions are available from some equipment manufacturers that allow better access to difficult-to-spray areas. A good spray technique consists of the applicator maintaining the spray gun perpendicular (90 deg) or near perpendicular (0 $\pm$ 5 deg) at all times.

7-4. Thermal Spray Equipment Operation

Each type and source of thermal spray equipment should be set up and operated in accordance with the manufacturer's recommended procedures. Spray parameters should be optimized primarily for coating quality and secondarily for production rate.

a. Wire and powder flame spray.

(1) Oxygen and fuel gas flow rates. The use of oxygen and fuel gas flow meters allows for the best control of the flame and thus higher spray rates. Under conditions of continuous use, the actual oxygen and fuel gas flow rates and pressures should remain nearly constant and, ordinarily, should not deviate from the set values by more than 5 percent.

(2) Atomization air pressure. Compressed air should be oil- and water-free. Accurate air regulation is necessary to achieve uniform atomization. Under conditions of continuous use, the actual atomization air pressure and flow volume should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent.

(3) Wire feed rate. The wire feed rate should be adjusted to properly optimize the time spent in the flame. Excessive feed rates may result in inadequate or partial melting of the feedstock and may produce very rough deposited coatings. Too slow a feed rate may cause the wire to be overoxidized and will produce coatings of poor quality. Under conditions of continuous use, the actual wire feed rate should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent.

(4) Powder feed rate. The powder feed rate should be adjusted to properly optimize the time spent in the flame. Excessive feed rates may result in inadequate or partial melting of the powder and may produce very rough deposited coatings. Too slow a feed rate may cause the powder to be overoxidized and will produce coatings of poor quality. Under conditions of continuous use, the actual powder feed rate should remain nearly constant and, ordinarily, should not deviate from the set value by more than 10 percent. The powder feedstock is typically

represented by a range of particle sizes. The various sized powder particles should be consumed at nearly the same rate and should not undergo a size segregation in the hopper.

(5) Air cap selection. A choice of air caps is available for powder flame spray equipment but not for wire flame spray. Wire flame spray is limited to a relatively small-diameter round spray pattern. Air caps for powder flame spray include fan (oval) and round spray patterns.

b. Arc spray.

(1) Power. In general, the higher the power output of the direct current power supply, the greater the possible production rate of the unit. Under conditions of continuous use, the actual current output should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent. Power supplies that are adequately sealed may be operated in dusty atmospheres and do not need to be isolated from the thermal spray operation. DC power supplies rated as high as 600 A are common. A lightweight power supply mounted on pneumatic tires will have added portability. The adhesion and deposit efficiency of the thermal spray coating is dependent on the power. There is an optimal amperage for each coating material that may further depend on wire diameter and the equipment model.

(2) Voltage. The voltage should be adjustable to accommodate different wire materials. Voltage should be set to the lowest level consistent with good arc stability. This will provide smooth dense coatings with superior deposit efficiency. Higher voltages increase thermal spray particle sizes and produce rougher coatings with lower densities. Under conditions of continuous use, the actual voltage should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent.

(3) Wire feed rate. The wire feed mechanism should be designed for automatic alignment. Manual alignment of the wires is time consuming and inexact. The wire feed mechanism must be capable of providing wire at a rate commensurate with the power consumption of the unit. Under conditions of continuous use, the actual wire feed rate should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent.

(4) Atomization air pressure. Under conditions of continuous use, the actual atomization air pressure and flow volume should remain nearly constant and, ordinarily, should not deviate from the set value by more than 5 percent. Lower atomization air pressures will produce rougher coatings with lower densities.

(5) Air cap selection. A choice of air caps is available for arc spray equipment. Air caps for arc spray include fan (oval) and round spray patterns. Some air caps are adjustable.

(6) Cable length. Most manufacturers offer optional cable packages that allow operation up to 30 m (100 ft) from the power supply. Longer cables provide added flexibility for thermal spraying in the field.

(7) Wire tips. Wire tips that hold and align the wires as they enter the arc zone are subject to wear. Properly designed equipment will allow cooler operating temperatures which will prolong tip life and reduce maintenance time. Easy-to-change tips are also beneficial.

(8) Arc shorting control. Arc shorting is a phenomenon wherein the arc shorts and must be restarted. Shorting sometimes requires that the wire ends be manually clipped before the arc is restruck. This operation can be very time consuming. Sometimes during arc shorting, lumps of unmelted wire are sheared off and deposited on the substrate resulting in poor coating quality. An added feature available on some arc spray equipment will control arc shorting.

7-5. Coverage of Thermal Spray Coatings

Nominal values for deposit efficiency, spray rates, and coverage of thermal spray coatings are available in the literature and from manufacturers. Actual rates may vary widely, depending on the actual equipment used, spraying parameters, operator experience, complexity of the item being coated, and whether the work is performed in the shop or in the field. The deposit efficiency is defined as the percentage of material sprayed that is actually deposited on a large flat surface. Table 7-2 presents deposit efficiencies for different thermal spray materials and processes. Table 7-3 shows the amount of material required to coat a unit area with a given thickness of coating. Table 7-4 lists spray rates (kg/hr) for the different processes and materials. Table 7-5 presents the equivalent coverage rates. This information is presented as a general guide and should not be used for cost estimating.

Table 7-2
Deposit Efficiency of Thermal Spray Processes

Material	Wire Flame Spray percent	Powder Flame Spray percent	Arc Spray percent
Zinc	65-70	85-90	60-65
Aluminum	80-85	85-90	70-75
85-15 Zn-Al	85-90	N/A	70-75

Table 7-3
Weight of Material Required for Coating a Given Area (kg/m^2/µm (lb/ft^2/mil))

Material	Wire Flame Spray	Powder Flame Spray	Arc Spray
Zinc	0.0098 (0.050)	0.0076 (0.039)	0.0110 (0.056)
Aluminum	0.0027 (0.014)	0.0027 (0.014)	0.0029 (0.015)
85-15 Zn-Al	0.0070 (0.036)	N/A	0.0093 (0.048)

Table 7-4
Spray Rates (kg/hr (lb/hr))

Material	Wire Flame 2.4-mm (3/32-in.) wire	Wire Flame 3.2-mm (1/8-in.) wire	Wire Flame 4.8-mm (3/16-in.) wire	Powder Flame Spray	Arc Spray (per 100 amps)
Zinc	9.1 (20.0)	20 (44.0)	30 (66.1)	14 (30.8)	18 (39.6)
Aluminum	2.5 (5.5)	5.4 (11.9)	7.3 (16.1)	6.8 (15.0)	2.7 (5.9)
85-15 Zn-Al	8.2 (18.0)	18 (39.6)	26 (57.3)	N/A	16 (35.2)

Table 7-5
Coverage Rates (m^2/hr/µm (ft^2/hr/mil))

Material	Wire Flame 2.4-mm (3/32-in.) wire	Wire Flame 3.2-mm (1/8-in.) wire	Wire Flame 4.8-mm (3/16-in.) wire	Powder Flame Spray	Arc Spray (per 100 amps)
Zinc	944 (2190)	2120 (4930)	3070 (7130)	1960 (4550)	1100 (2560)
Aluminum	873 (2030)	1890 (4390)	2530 (5880)	2600 (6040)	826 (1920)
85-15 Zn-Al	1180 (2740)	2620 (6090)	3800 (8830)	N/A	968 (2250)

7-6. Sequence of Thermal Spray Application

Surfaces that will be thermal sprayed must be clean before application of the thermal spray coating. Cleaning, thermal spray application, and sealing should be scheduled so that dust, overspray, and other contaminants from these operations are not deposited on surfaces ready for thermal spray coating or sealing. Surfaces that will not be thermal sprayed should be protected from the effects of blast cleaning and thermal spray application. Special care should be taken to prevent entry of abrasive and thermal spray dusts into sensitive machinery and electrical equipment. Painted surfaces adjacent to surfaces receiving thermal spray coatings should be adequately protected from damage by molten thermal spray particles. Thermal spray coatings should not be applied closer than 2 cm (3/4 in.) to surfaces that will be welded. Surfaces that have been cleaned for thermal spray should be sprayed as soon as practicable. The first thermal spray coat should be applied before the appearance of rust bloom on the surface or within 4 hr of blast cleaning, whichever is sooner. In some cases, it may be possible to hold the appearance of the blast cleaned substrate for longer periods of time using a dehumidification system that supplies dry air to the spray enclosure.